TRANSMETA
CORPORATION

Crusoe

A Low-Power Microprocessor for the Internet Era

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Overview

- **From Industrial Age to Internet Age**
  - Industrial Age - From the electric factory to electric motors
  - Information Age - From the Mainframe to PC's
  - Internet Age
    - Core technology trends: Mobile Internet computing, power density limits and bandwidth abundance
    - New design imperative: From wasting watts and transistors to wasting bandwidth and saving watts
- **A Microprocessor for the Internet Age - Crusoe**
  - Integration, efficiency, compatibility, flexibility
  - Maximize energy efficiency!
- **Crusoe Applications**
  - Anytime, Anywhere Internet computing ("waste bandwidth")
  - High-density computing servers ("save watts and transistors")

Industrial Age

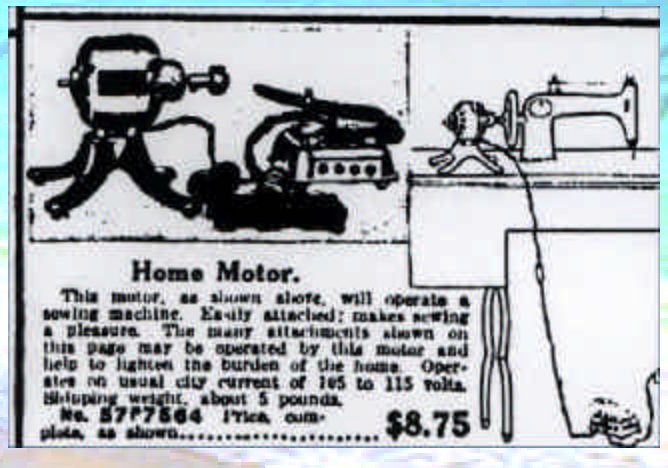
Paradigm Shift in Energy Distribution

19th Century

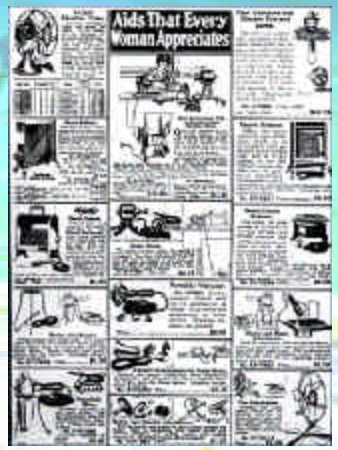
The Electric Factory

20th Century

The Home Electric Motor



"Peripherals"

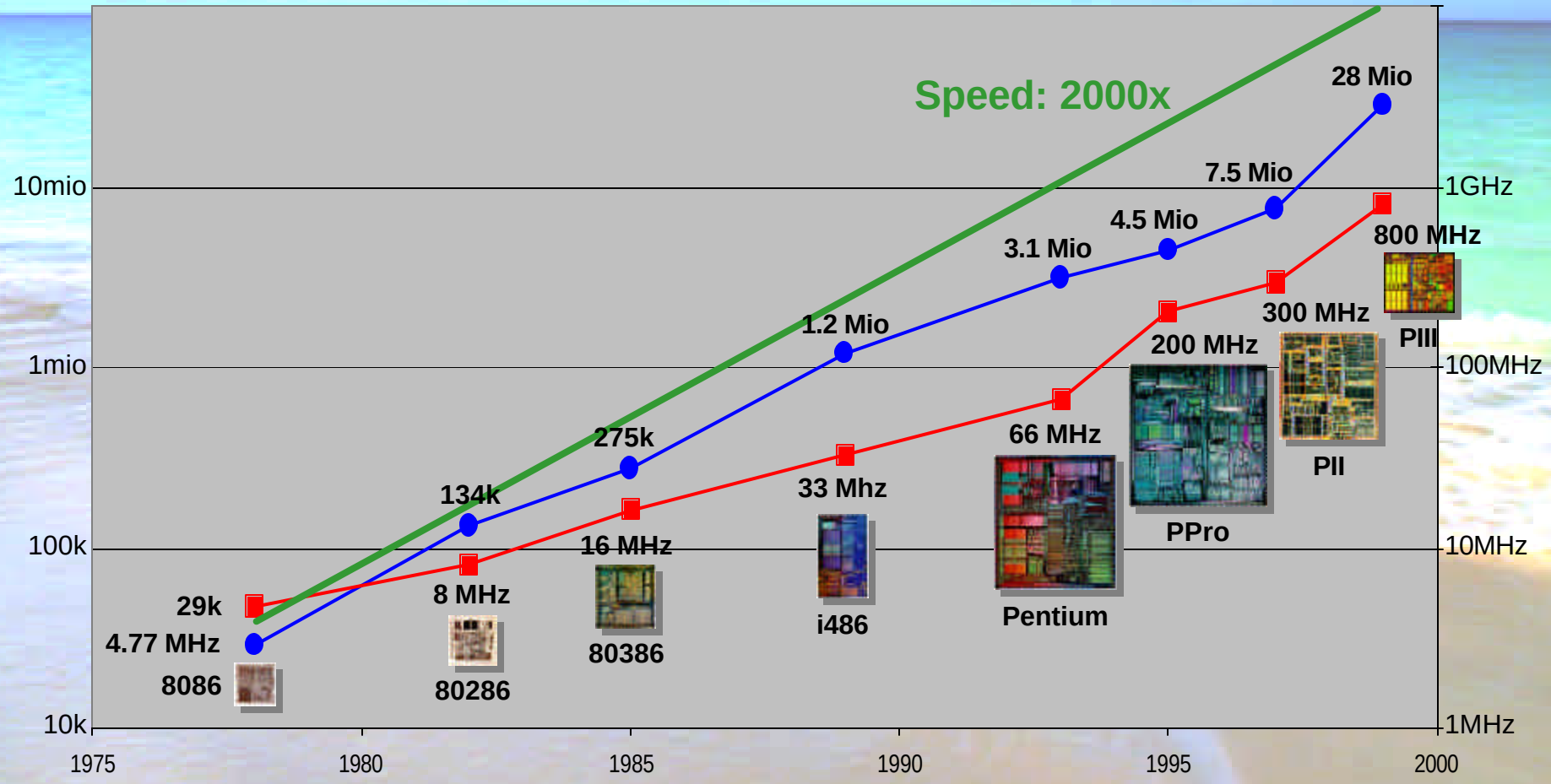


- **Power (electricity) became an abundant resource**
- **That is, power became virtually free**
  - Use it everywhere (e.g., the "Home Electric Motor")

Information Age

Moore's Law, 1970

"The number of transistors on the die doubles every 18 months."



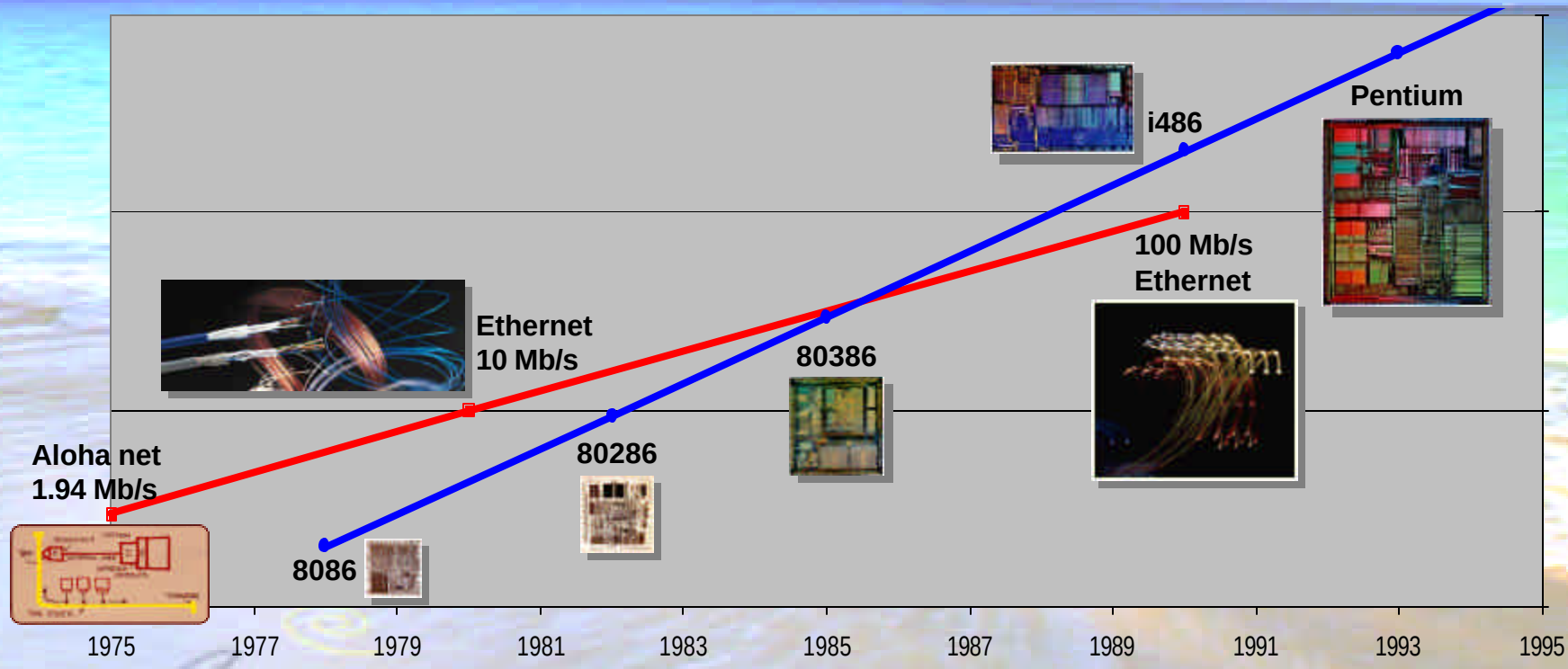
Information Age
Implications of Moore's Law

- **Transistors became an abundant resource**
- **That is, transistors have become virtually free**
  - Put them everywhere (prerequisite: abundant power)
  - General-purpose Personal Computer (PC)
- **Business models based on scarce transistors collapsed**
  - From many users/computer to one computer/user
  - The fall of IBM (mainframes)
  - The rise of Microsoft and Intel (PCs)

The Bandwidth Gap of the ’90s

CPU Speed vs. Bandwidth

In the last century, a processing/bandwidth gap increased one order of magnitude per decade.



- **Bandwidth was becoming a scarce resource**
  - Substitute for it. And how?

Bandwidth Equals Switching

Shannon's Theorem, 1948

"Switching and power can substitute for bandwidth."

- **Switching**
  - Transistors can compensate for limited bandwidth
  - Key problem - channel capacity
  - Solution
    - Waste transistors - multiplex, cache, compress, encode, correct, buffer, route and store information
- **Power**
  - Amplification can compensate for limited bandwidth
  - Key problem - signal to noise ratio of channel
  - Solutions
    - Waste power - increase signal strength ("long and narrow" paradigm)
    - Waste bandwidth - increase information redundancy, allowing more loss (increased spectral efficiency, "wide and weak" paradigm)

The Laws of the Microcosm

Key Technology Driving Factors

- Abundant power (industrial revolution)
- Abundant transistors (information age)
- Scarce bandwidth ("copper"-sphere)

The Centrifugal Law of the Microcosm

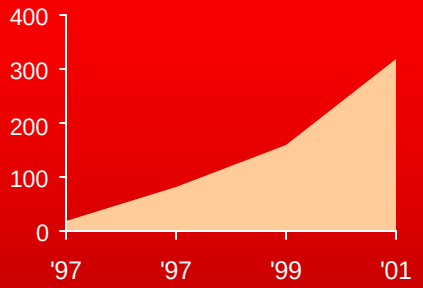
- **General-purpose devices in network periphery**
  - Intelligence (processing) gravitates towards network periphery
  - Tethered "Fat Clients" and PC's
- **"Soft" network core (internetworking layer)**
  - Software intelligence ("switching")
- **Organizations and markets**
  - Empowering the individual: Flat hierarchies and disintermediation
  - "Outsourcing", "business re-engineering", etc.


All of This is About to Change

Power: Abundant ✍ Limited

Mobile Internet Computing Transforms the PC Market

Growth



Projected Growth

143%

1999-2002

Source: Dataquest 3/99

Capabilities

Thin & lights and Mini-Notebooks will be 65% of market by 2002

Thin & light becoming even thinner:
1-1.5" today
.85-1.25" in 2002

Source: Intel 1999

User Demands

Ease of use

93% say their battery "doesn't last long enough"

Portability

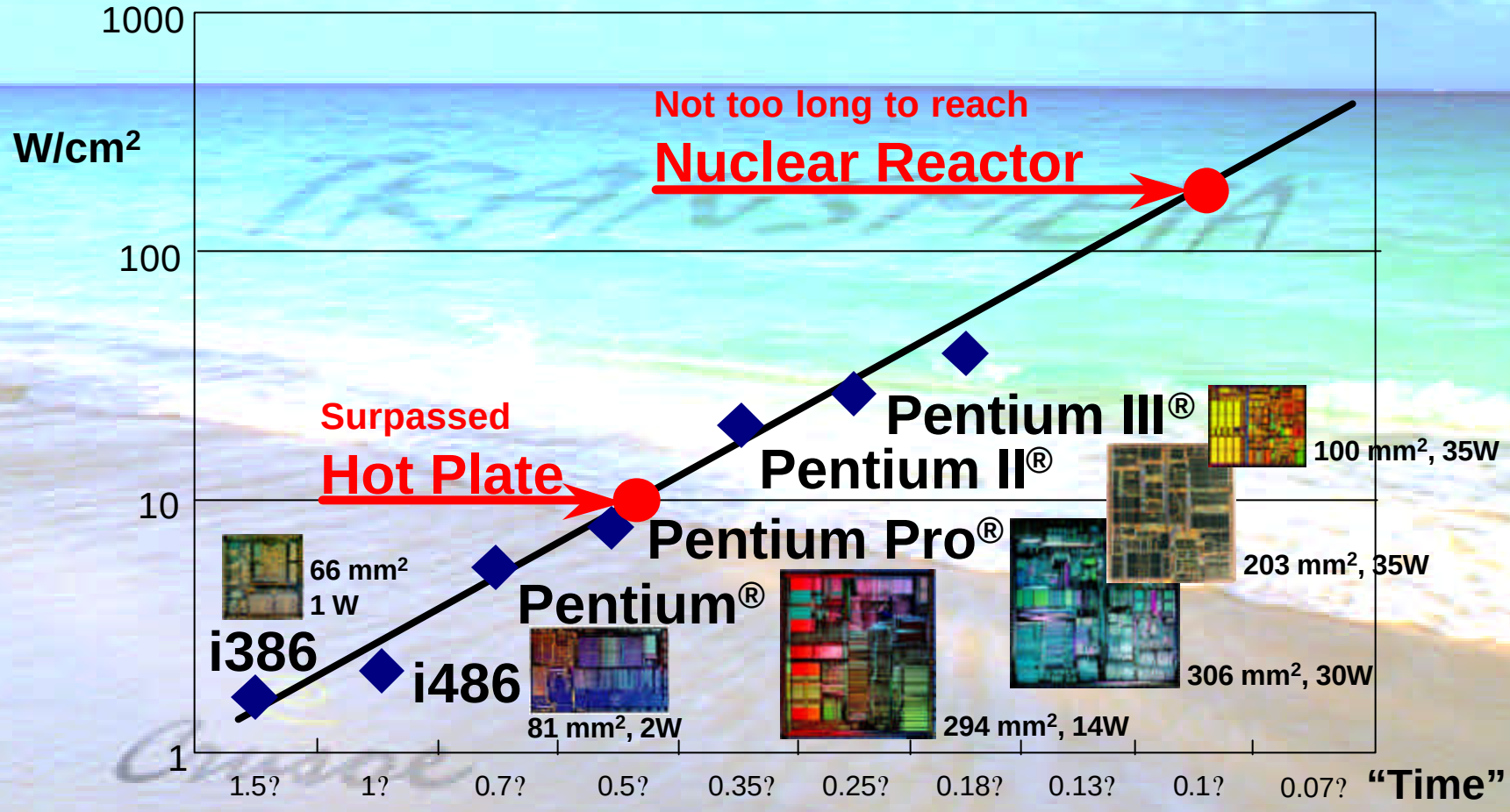
82% say their systems are "too heavy"

Source: IDC 12/99

Emergence of wireless connectivity increases importance of battery life

Transistors: Abundant ✍ Limited

Power Density - The Key Design Challenge



Source: Fred Pollack, Intel. New Microprocessor Challenges in the Coming Generations of CMOS Technologies, MICRO32

Bandwidth: Scarce ✍ Abundant

Dramatic Bandwidth Acceleration in the 21st Century

- Bandwidth growth is now outpacing Moore's Law by a factor of 10
- Bandwidth will substitute for transistors
- New computing paradigm will be based on the runaway expansion of bandwidth (land and air)

The Gilder Paradigm

Key Technology Driving Factors

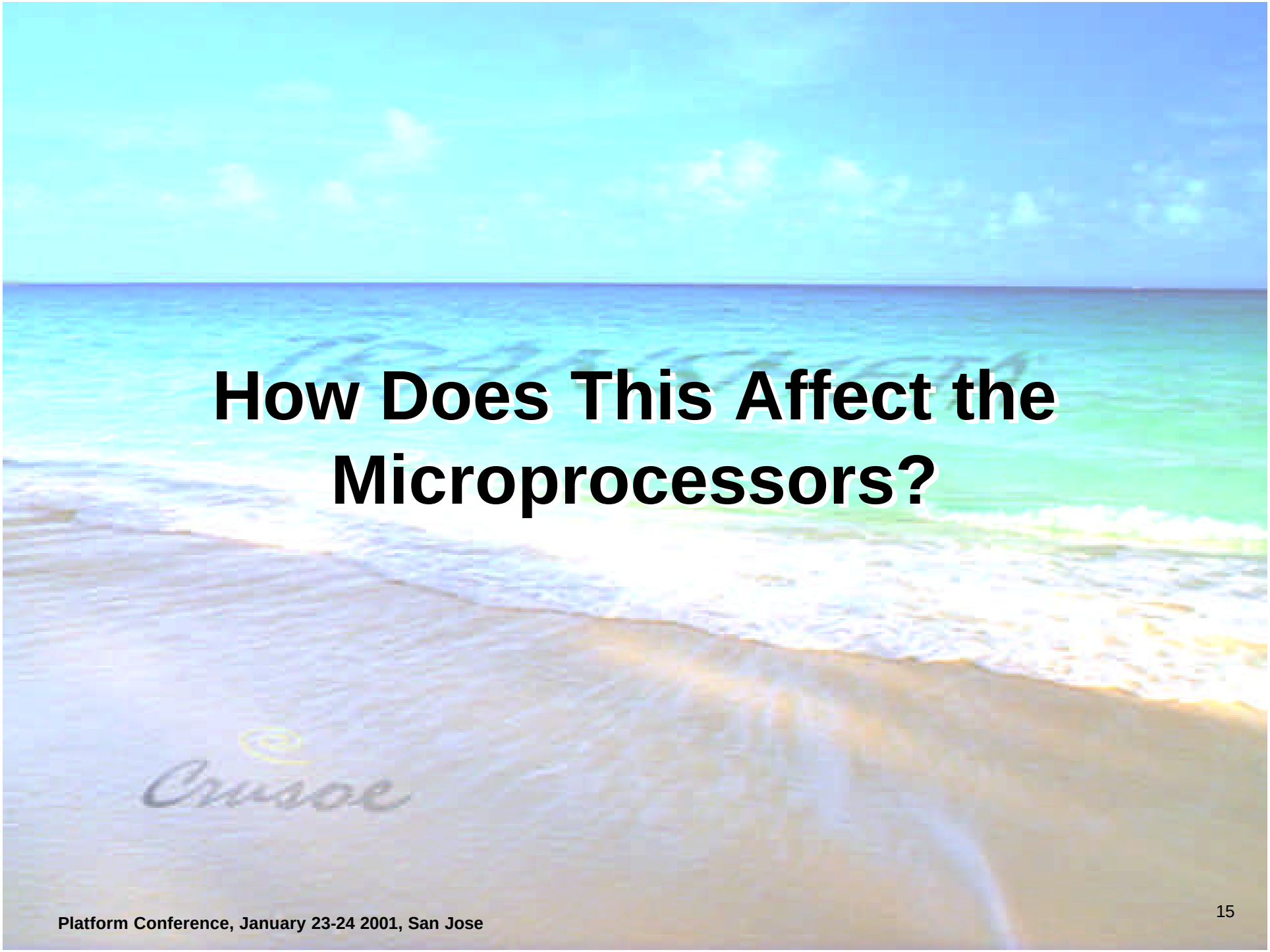
- Power constraints (wireless Internet access)
- Transistor constraints (power/heat density)
- Abundant bandwidth ("fiber"-sphere and 3G/UMTS wireless)

The Emerging Paradigm

- **From one computer/user to many computers/user**
  - "Electric factory": Mainframe
  - "Home electric motor": Personal Computer (PC)
  - Now moving beyond the "Home Electric Motor" stage of computing
  - People relate to things, not electric motors or PC's!
- **Digital convergence**
  - General purpose PCs and consumer electronics will converge into network-oriented smart devices with corresponding new services

The Internet Age
From Microcosm to Netsphere

- **Network core (internetworking layer) will "harden"**
  - All-optical fiber-sphere with optical repeaters ("wide and weak")
- **Network periphery will soften**
  - Services migrate into network periphery, bundled with Internet (DSL)
  - The rise of calm computing (computers retreat into background)
  - Wireless hi-res audio-visual devices ("satellites" - glorified displays)
  - Microprocessor will become adaptable peripherals with new software
  - Key properties of emerging microprocessors (and devices): Integration, efficiency, compatibility, flexibility!
- **Organizations and markets**
  - Virtualization



How Does This Affect the Microprocessors?

The Internet Processor

Integration, Efficiency, Compatibility, Flexibility

"If the old paradigm was waste watts and transistors, the new paradigm will be waste bandwidth and save watts!" George Gilder

- Microprocessors become an adaptable peripheral

The Solution – Crusoe

Microprocessor Architecture

Crusoe is the Sum of

= **Code Morphing Software (CMS)** **+** **VLIW Engine**

- "Morphs" PC into VLIW Engine
  Translates x86 instructions into optimized VLIW molecules
- Learns and improves with time
- Evolves to new devices, usage models and content types

- 128-bit **V**ery **L**ong **I**nstruction **W**ord (VLIW) processor
- Fewer transistors
- "Lean and mean"

¾ + ¼

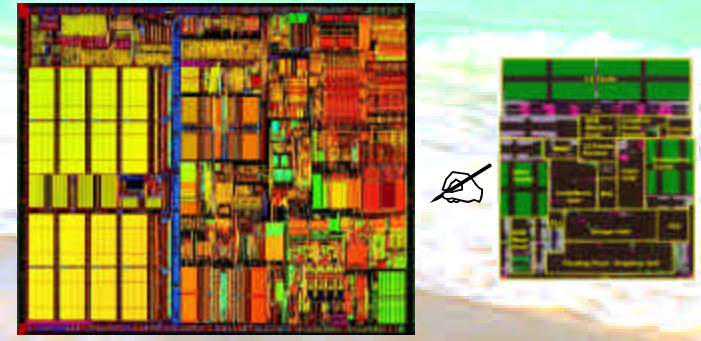
Maximize Efficiency

No Hardware is the Best Low-Power Hardware

$$Power = (Capacitance \times Voltage^2 \times Frequency)/2$$

- **Transmeta innovation - Code Morphing Software**
- **Effect - replace millions of logic transistors with software**
  - … and transistors translate into capacitance
- **Benefit - significantly reduces power consumption**

Pentium III **Crusoe**



~140 mm² **73 mm²**

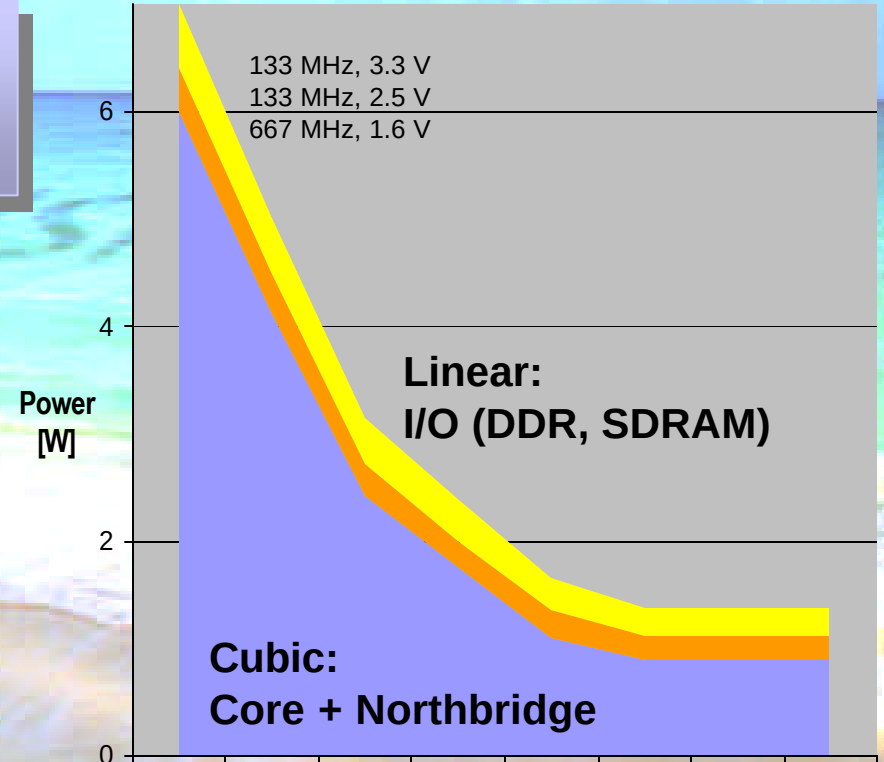
(including 256 kB L2 cache)

Maximize Efficiency

LongRun - Performance on Demand

$$Power \propto c \times v^2 \times f$$

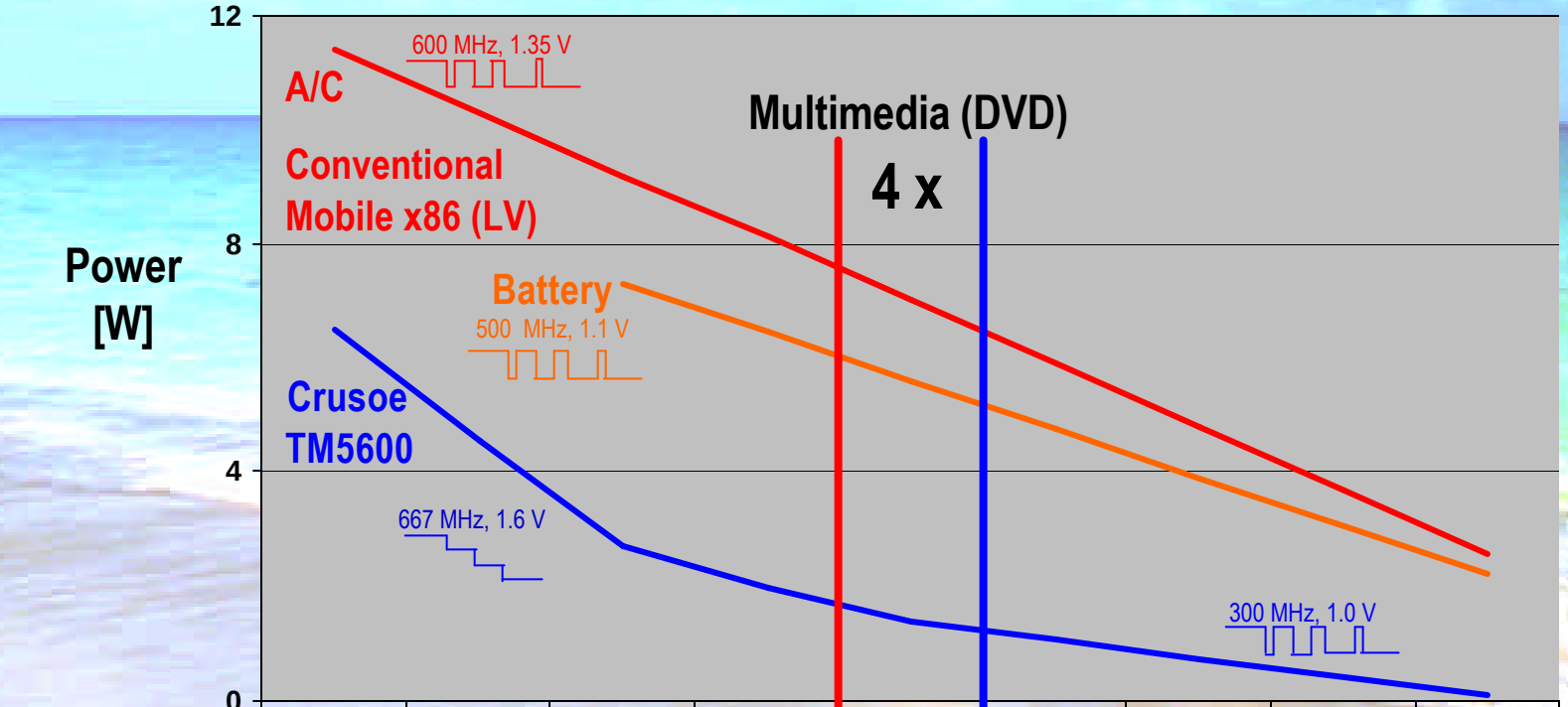
- **Dynamically adapt both frequency and voltage to performance demands**
- **Mechanisms in hardware**
  - Fully programmable
- **Policies in CMS**
  - Adapt f to demand
  - Reduce v proportionally
  - Cubic power savings!



	Normal	12.5%	25.0%	37.5%	50.0%	62.5%	75.0%	87.5%
SDR	0.6	0.5	0.4	0.4	0.3	0.2	0.2	0.2
DDR	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.2
Core+NB	6.0	4.1	2.4	1.7	1.1	0.9	0.9	0.9

The LongRun Effect

Power Profiles



	Normal	12.5%	25.0%	37.5%	50.0%	62.5%	75.0%	87.5%	C3
TM5600+NB	6.5	4.6	2.7	2.0	1.4	1.1	0.8	0.4	0.1
A/C	11.4	10.3	9.2	8.1	7.0	5.9	4.8	3.7	2.6
Battery			7.3	6.5	5.6	4.8	3.9	3.1	2.2

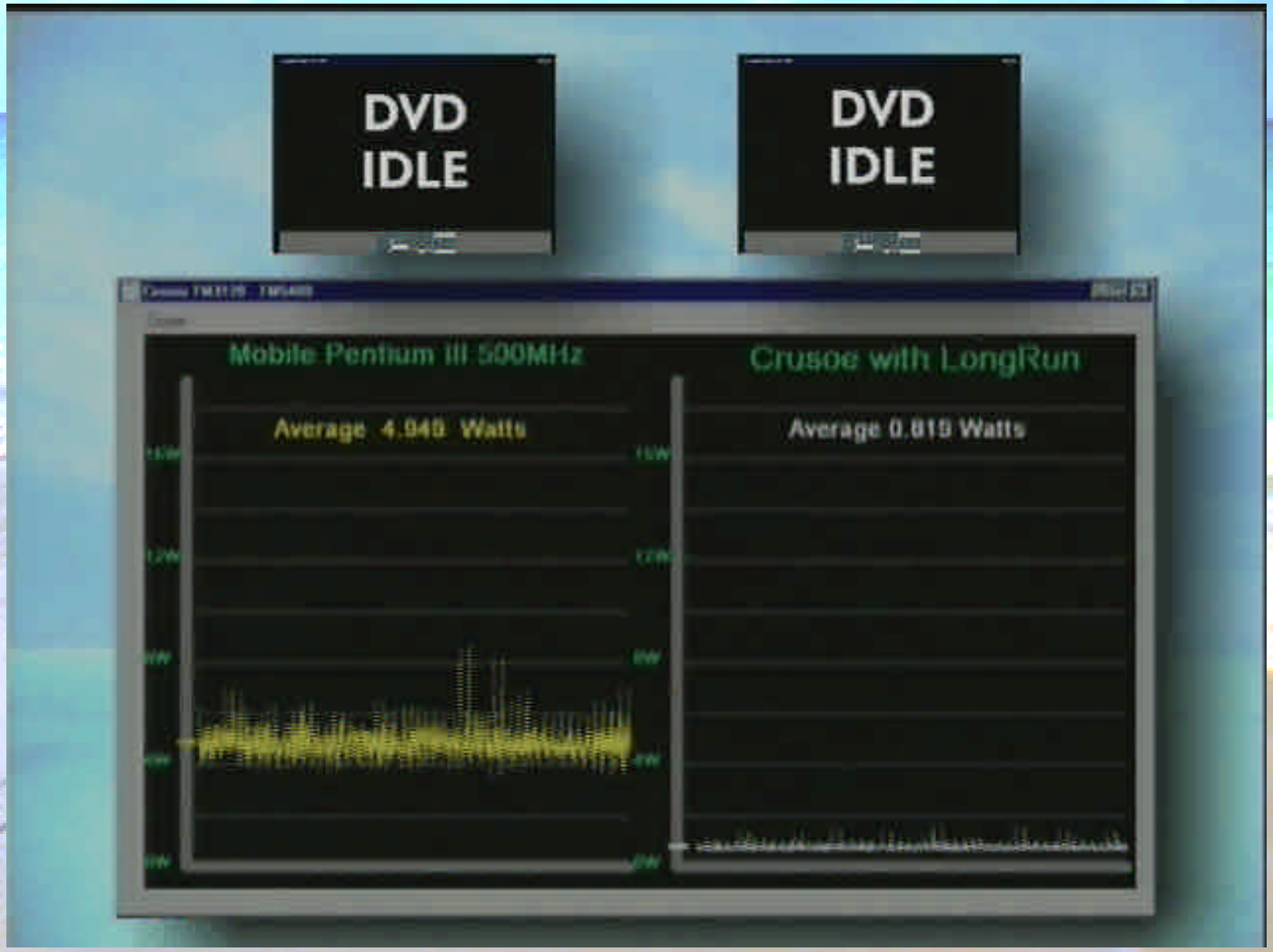
Notes

[1] Power numbers include Northbridge

[2] DDR-only configuration

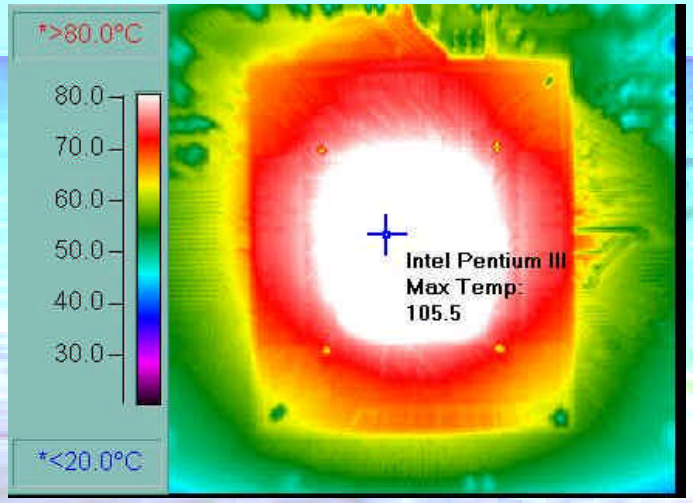
The LongRun Advantage

DVD Playback – Performance on Demand



The Crusoe Advantage

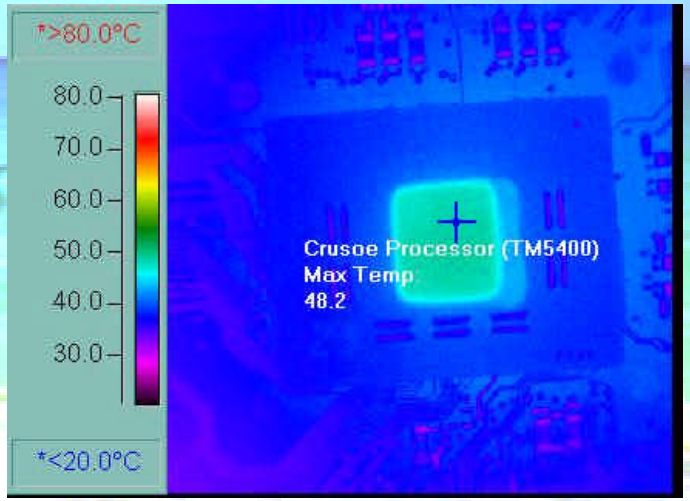
DVD Playback - Thermal Comparison



Conventional Mobile x86 Processor

105.5º C 221.9º F

Active thermal solution required (Fan or overload protection)



Crusoe TM5600 Processor with LongRun

48.2º C 118.8º F

Passive thermal solution (No fan or overload protection)

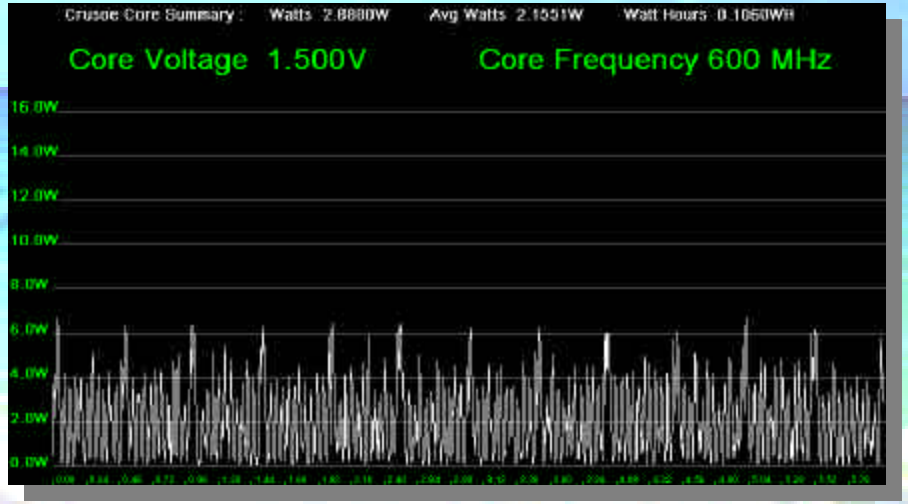
The Crusoe Advantage

Rapid Evolution Through Software

CMS 4.1

SDR

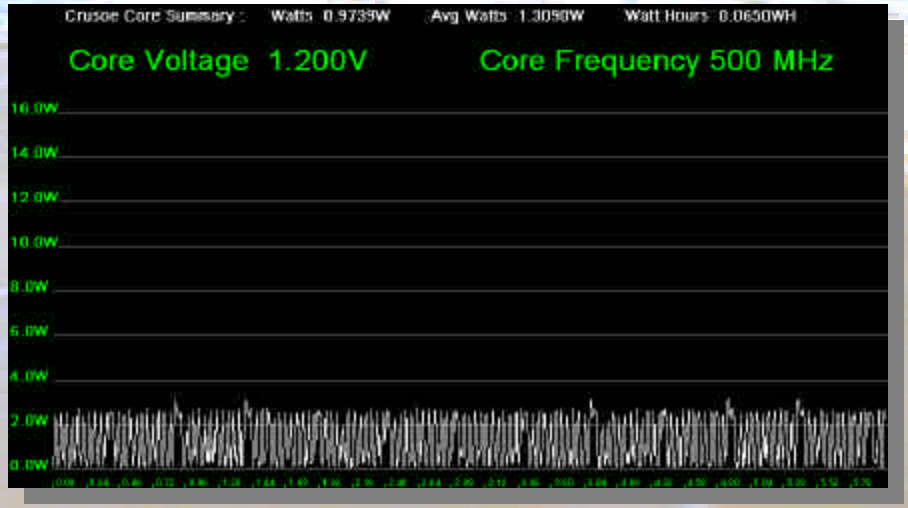
Q3 2000



CMS 4.2

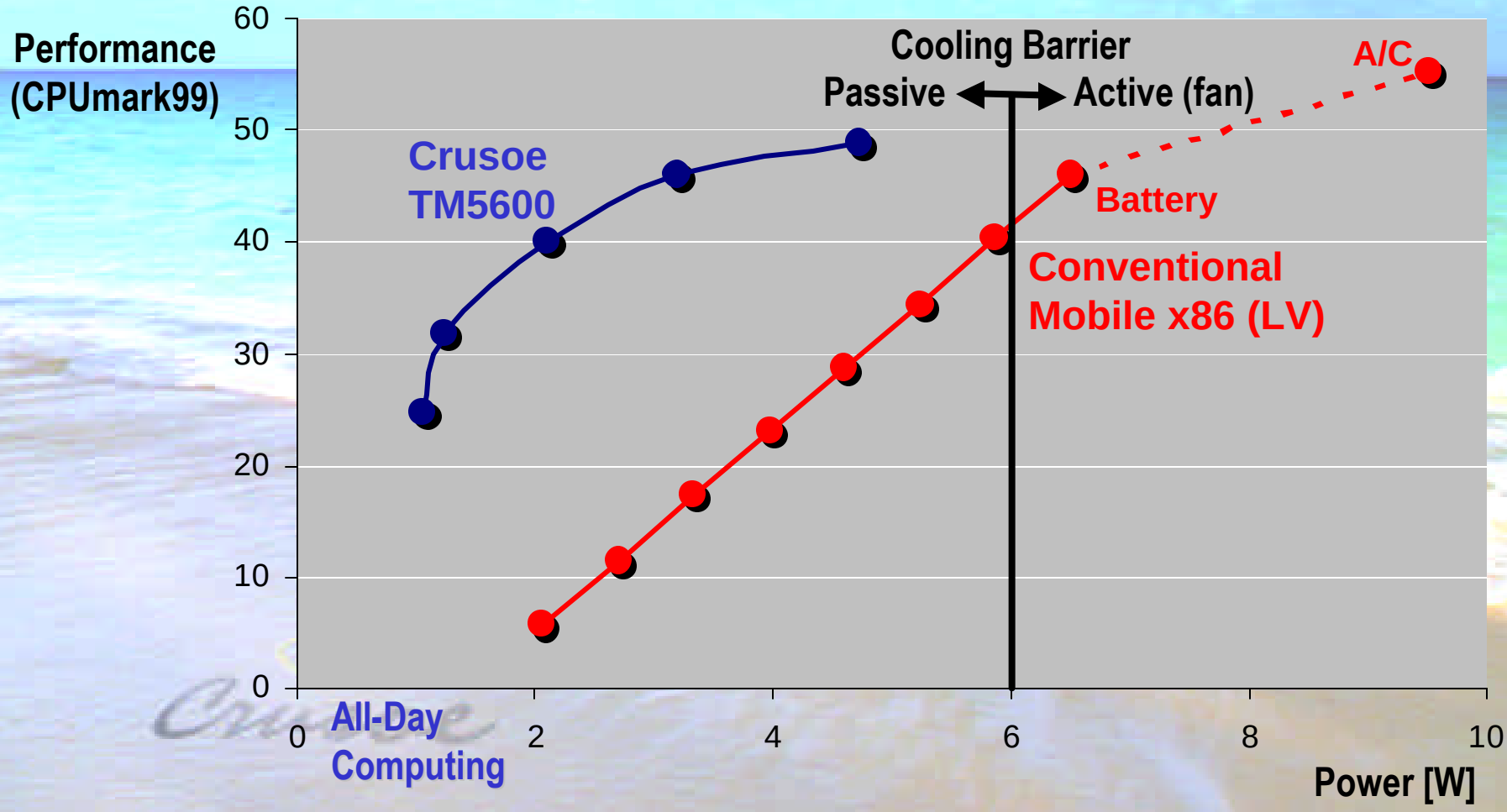
DDR

Q4 2001



Energy Efficiency

Superior Performance in Small Form Factors




How About the Devices?

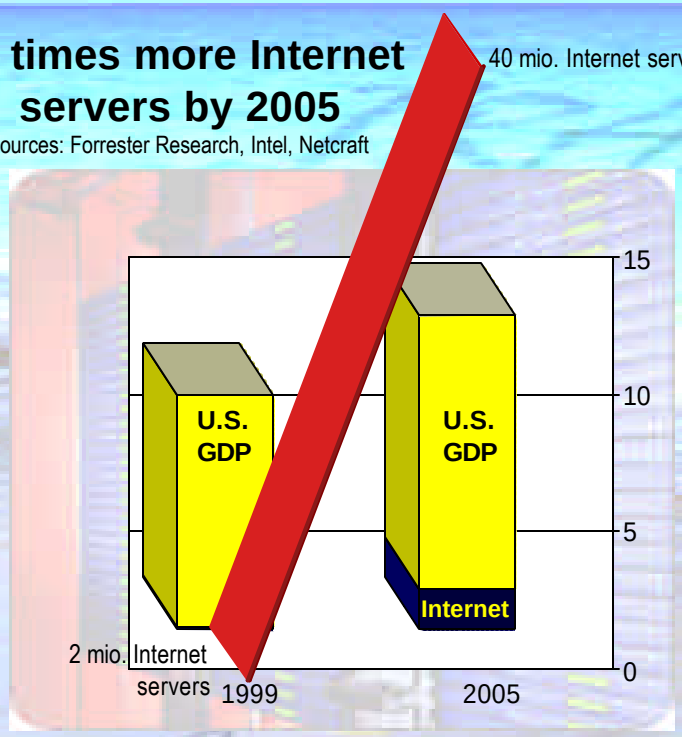
The Internet Age

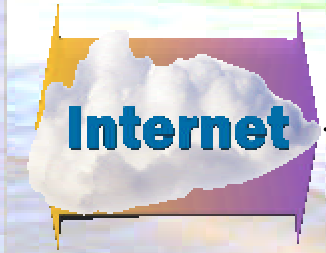
Integration, Efficiency, Compatibility, Flexibility

"We are moving beyond either a PC-centric or TV-centric to a more network-centric future." Teruaki Aoki, President Sony CE

20 times more Internet servers by 2005

Sources: Forrester Research, Intel, Netcraft





xDSL
Cable

Gateway

802.11
3G

? **Computational density drives server designs**

? **The rise of calm computing**

Sony Web-Broadcasting Laptop

Anytime, Anywhere Internet Computing

The Sony Crusoe laptop with a video camcorder attached to the side.
Users can shoot and send video images to the Internet.
The video lens and display rotate 180 degrees.

High-Density Computing

Power Density Drives Server Designs

- **The CPU power dissipation traditionally constrains computational density**
- **Crusoe: Ultra low-power and low-heat allows to increase CPU packing density by 8x**
- **System benefits**
  - Maximum computational density
  - Less total power consumption
  - Less weight
  - Smaller footprint

Cobalt RaQ Microserver Farm

Summary

- **Past century - Microcosm**
  - Abundant power and transistors, scarce bandwidth
  - The centrifugal law of the Microcosm
    - General-purpose computers migrate to network periphery (PC's)
    - "Home electric motor" stage of computing
    - Organizations & markets: Flat hierarchies & disintermediation
- **Next century - Netsphere**
  - Abundant power and transistors ✍ abundant bandwidth
    - Anytime, Anywhere Internet connectivity, and rise of calm computing
    - Organizations & markets: Virtualization
    - New fortunes in ever-changing transmutations of multimedia and wireless computing devices will dwarf yields of cable and cellular
  - The window of opportunity opens "wide and weak"


Crusoe